A system of transformable crosspieces to block harmful combustion product propagation in tunnels

Omar LANCHAVA [1, 2], Nicolae ILIAS [3], Sorin Mihai RADU [3], Giorgi NOZADZE [1], Marad JANGIDZE [1]

[1] *G. Tsulukidze Mining Institute, Tbilisi, Mindeli Street 7, Georgia*
[2] *Georgian Technical University, Tbilisi, Kostava Street, 77, Georgia*
[2] *University of Petrşani, Petroşani, Universităţii Street 20, Romania*

Abstract: Controlling the events and processes caused by fires is one of the key issues of all projects dedicated to the fire safety of tunnels. These processes are characterized by the dynamics of the propagation of high temperature, smoke and toxic combustion products around the seat of fire and in tunnels. With longitudinal ventilation, two main parameters are to be considered: the critical velocity and the backlayering length. An important impact on both parameters is exerted by the proposed system of flexible crosspieces, which, by increasing the aerodynamic resistance of a tunnel, makes it possible to reduce the speed of propagation of harmful factors of fire through the tunnel. Moreover, with certain limitations, the given crosspieces can be used to divide the tunnel into small sections what, among other things, will hinder the propagation of fire for a certain time. Thorough theoretical and experimental study of the mentioned transformable crosspieces, as well as the development of their various structures and operating principles is necessary to ensure the safety of traffic tunnels. The present article proposes a novel technology of light transformable crosspieces, which can be used in both, the existing road tunnels and the ones planned to design.

Keywords: fire development scenario in tunnels, transformable crosspieces, aerodynamic resistance, evacuation, saving life.

1. Introduction

Following massive tunnel fires all over the world, the European Union has paid much attention to the Trans-European network (TEN), where the safety of its existing and planned tunnels is prioritized.

For the TEN tunnels with their length exceeding 500 m, the European Parliament and the European Council issued Directive EC2004/54 regarding the minimum level of safety. Under the Directive, the fire safety expenses for road tunnels in the EU countries vary between €2.6 and 6.3

billion. €2.6 billion is needed for ventilation systems and their improvement technology associated with fewer expenses as per the Directive [1-3].

Famous fires in recent years, such as the ones occurring in Mont Blanc, Gotthard and Viamala tunnels, urged further studies, which propose the methods to improve the existing tunnel ventilation and safety systems. A quite detailed review analysis of the scientific studies in the given field is given in article [4]. Besides, recent vigorous attempts to realize the ideas based on the obtained results as evidenced by their patent publications are noteworthy [5-7].

For the tunnels under construction, the method to divide them into short sections by means of fireproof barriers to hamper the spread of fire and its harmful factors was proposed; however, in "old" tunnels, following their geometry, the realization of such capital construction projects is complicated, as there is no sufficient space for this method to use [8, 9].

2. Idea, results and discussion

The proposed idea implies improving the ventilation technology in case of fire to impede the propagation of harmful combustion products (carbon oxides and soot) and to save lives, as fires in road tunnels are still a highly risky challenge and a subject of an intense engineering study. It was developed in line with the issues studied by us in advance [10-14].

The study idea is based on an artificial increase of aerodynamic resistance of a tunnel by using a transformable system, which will hinder the propagation of combustion products, but not the movement of people. It will also help isolate the polluted and the clean air currents at the expense of density difference. As a result, the ventilation system will be more flexible in saving people's lives, as the time allowed for evacuation will increase.

Usually, a transformable system is used in places with a generally complicated access for people. A seat of fire in a road tunnel is one such place, as the basic means for people to save from such a tunnel is self-evacuation.

The transformable barriers will be installed in the road tunnels along the perimeter of the tunnel cross section. They are controlled by means of autonomous electrical and mechanical drive system. The electrical drive system will be possible to control by means of both, central and local control panels. The transformable barriers will be placed in a tunnel on the localization site, according to the geometry of the perimeter. The sites of niches in the tunnel may be considered as localization sites, with the distance between them of approximately 300 m in line with the effective standards of a number of countries. Figure 1 presents a system of flexible barriers.

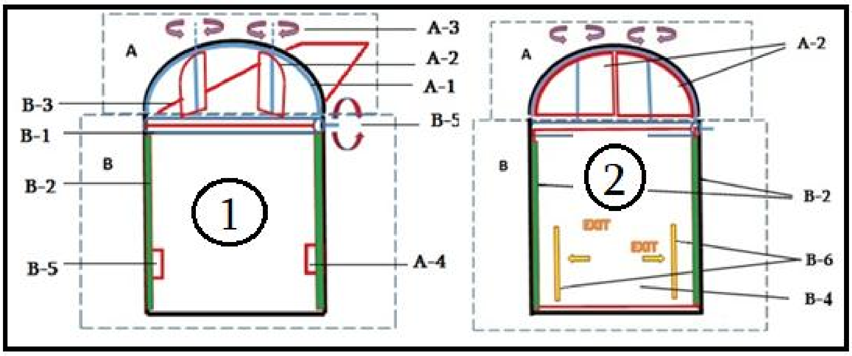

Fig. 1. Location of flexible barriers along the tunnel perimeter:
1 – folded (in a standby mode); 2 – deployed (active)

The proposed technology may be used to extensively change the intensity and propagation of thermal and toxic currents caused by fire by varying aerodynamic resistance. This makes the ventilation system more flexible and comfortable to evacuate the people from an extraordinary situation. Thus, the use of transformable barriers will allow reducing the area of propagation of combustion products at the expense of increased aerodynamic resistance and inhibited spread of combustion products. As a result, the chances of evacuation and time available for it are expected to increase.

Section A is made of an arch-shaped frame A-1 relevant to the tunnel ceiling, which is formed by and which contains the barriers made of A-2 fireproof plates, which, by means of the relevant kinematic diagram A-3, can partially or fully open or close the arched cross section, which is enclosed by frame of section A (See Figure 2). Section A is controlled by A-4 autonomous drive system by either central, or local control panel.

Section B is made of a rectangular frame, which encloses a rectangular cross section of a tunnel and a tunnel section designed for a vehicular traffic, which cannot be covered by section A following the tunnel geometry. The given rectangular frame is B-1. There are guiding channels B-2 fixed on the said frame along the tunnel walls and flexible fireproof barriers can move through them in line with the relevant kinematic diagram (See Fig. 2, Drawing 2). A folded barrier is in horizontal state B-3 in the ceiling, while, as deployed, it locks up a part of the tunnel cross section enclosed by frame B-1 either partially, or fully, as necessary. The latter situation is shown as state B-4. Thus, the given barrier, representing section B, is in a vertical position when activated. Section B is controlled with B-5 autonomous drive system by means of either central, or local control panel.

A two-section system of deployed (active) crosspieces is shown in Figure 1 (Drawing 2). The barrier filling (locking up) section B, which in a vertical state when in operation, is equipped with evacuation air-proof openings B-6, whose positions will be marked with bright luminiferous paint. By using these openings, people will be able to pass through the crosspiece in both directions. This will allow leaving or entering the enclosed area with continuously efficient crosspiece operation.

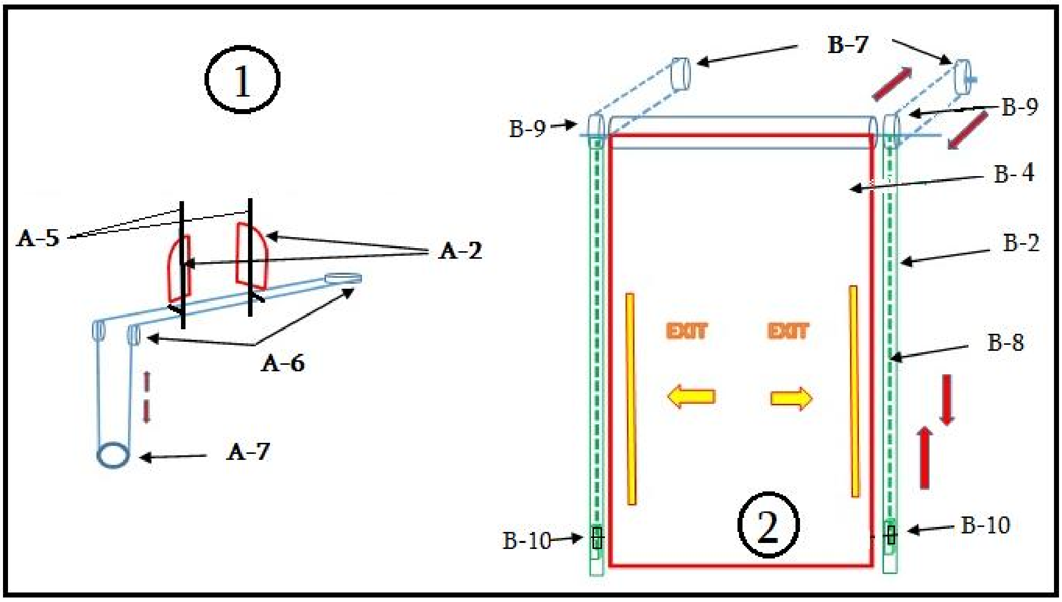

Fig. 2. Kinematic diagrams of sections A and B

An independent solution of section A was chosen following the individual structural solution of the arch sections of a tunnel and the fact that this section will have to operate in the heaviest thermal mode, as the heat flows developed as a result of fire will occur along the roof. For the tunnels with a rectangular or near-rectangular section, only one section B of a two-section system of transformable crosspieces can be used.

Description of the kinematic diagram of operation of section A

Each plate of the frame with a shape relevant to the tunnel ceiling of section A has its own rotation axis A-5 installed in the frame. The system of crosspieces of section A is equipped with an electrical drive and reserve mechanical system controlled remotely to rotate around its own axis A-

5, which is equipped with the network and autonomous power supply. The power supply source and the drive system will be installed in an appropriately sized fireproof box attached to the tunnel wall. The driving force of the electrical drive and reserve mechanical system will be transferred to the rotation axes of the crosspieces on one of the tunnel walls, at the height of 1 m from the tunnel roadway by means of a system of steel rope packs made of a light fireproof material in line with the kinematic diagram given in Drawing 1 of Figure 2.

Description of the kinematic diagram of operation of section B

A flexible fireproof crosspiece of section B is a dense rectangular material with high aerodynamic resistance made of the basalt fiber by considering the sizes of the given section, which will move through the vertical or horizontal guide channels. The channels will be installed according to the kinematic diagram given in Drawing 2 of Figure 2. Both edges of the flexible crosspiece are rigidly connected to B-8 traction chain system, which is installed and moves through guide channels. At the ends of the traction chain system and the cylindrical drum, there are gear rollers B-7 and B-9, which ensure folding and deployment of a flexible crosspiece at a regular speed by means of B-10 circular driving gears connected to the drive-reduction gear system B-5. The flexible crosspiece is laterally connected to the chains on the edges and together with them, moves around the rotating drum by means of gear B-9. The drum and gear B-9 ensure smooth folding and deployment of the crosspiece. B-3 marks a flexible rectangular crosspiece in a folded state (in a standby mode) and B-4 marks a deployed crosspiece (i.e. in operation).

The designation of section B is to properly deploy the flexible crosspiece installed in the main tunnel cross section by an operator in response to the concrete readings of detectors of toxic gases and temperature formed in the seat of fire in the tunnel what allows developing relevant aerodynamic resistance to obstruct the spread of air currents formed in the given cross section.

Flexible crosspiece B-3 (B-4) of section B is equipped with air-tight 2-meter-high self-closing evacuation sections B-6, which are designated for evacuation. They can be doubled as the sluices of some type or another, which allow evacuating people from a site localized by a crosspiece through the sections at the same time preventing intense spread of harmful factors from the given site.

Thus, the use of transformable crosspieces aims at improving the efficiency of the ventilation system during emergencies caused by fire. The above-described crosspieces can be used to divide a tunnel into short sections (See Fig. 3) what will allow hindering an uncontrolled propagation of combustion products in the tunnel by increasing the aerodynamic resistance of the latter. The proposed solution will allow controlling and minimizing the propagation of such life-threatening factors of the currents caused by fires of different degrees, as high temperature, hazardous increase in carbon oxides and soot concentration and reduction of oxygen concentration.

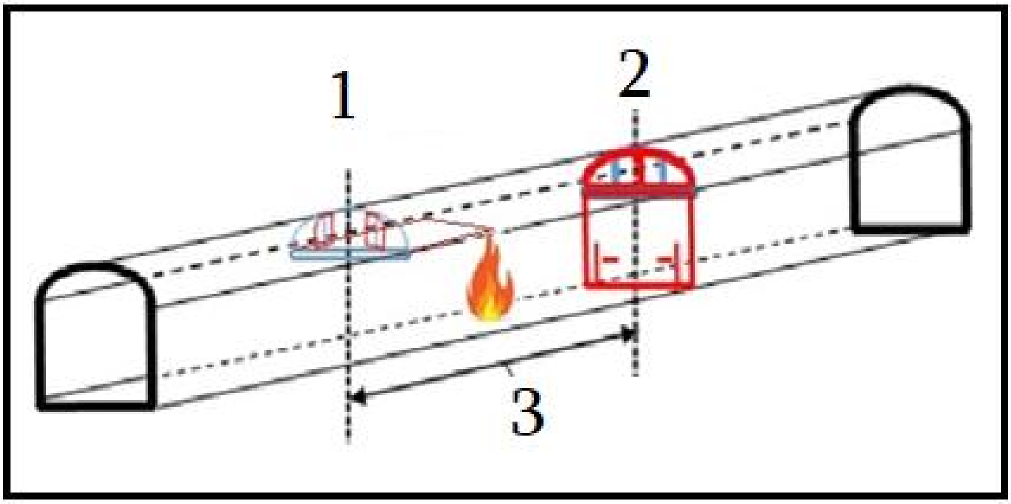

Fig. 3. Tunnel division by using transformable crosspieces: 1 – folded transformable crosspiece (in a standby mode); 2 - transformable crosspiece in operation (deployed); 3 – localized seat of fire

3. Conclusions

The technology to manufacture and operate a transformable system made of light, transformable and flexible fireproof crosspieces of variable aerodynamic resistance in road tunnels equipped with different types of ventilation systems is proposed.

The transformable system proposed by us, as compared to its presently available analogs, has the following advantages:

- Light structure owing to the use of fireproof basalt fiber materials as the crosspieces of the flexible system;
- Simple and swift installation: the whole structure of the equipment is possible to install on the tunnel walls with anchors without any other type of impact on the tunnel structure;
- Extensive resource to adapt to a tunnel infrastructure. The proposed structure is possible to connect to the tunnel control system either with wires, or wireless.
- Improved activation efficiency and reliability – the structure will be equipped with an autonomous and central power supply and control and communication systems.
- Competitive price owing to low material capacity and simple installation.

Acknowledgements

This work was supported by Shota Rustaveli National Science Foundation (SRNSF) [Grant number AR-19-1936, Project title “*Development and testing of transformable system to save life in road tunnel in case of fire*”].

References

1. D. Theologitis (2005) Euro transport, # 3, pp. 16 – 22.
2. UN, Economic and Social Council, Economic Commission for Europe (2001) *Report TRANS/AC.7/9*, p. 59.
3. UN, Economic and Social Council, Economic Commission for Europe (2002) *Report TRANS/AC.7/11*, p. 6.
4. Bettelini M., Rigert S., Seifert N. (2012) FLEXIBLE DEVICES FOR SMOKE CONTROL IN ROAD TUNNELS, Amberg Engineering Ltd., Regensdorf-Watt, Switzerland, 6th International Conference “Tunnel Safety and Ventilation”, pp 265-272, Graz.
5. Amelchukov Cergei Petrobich, Korotkov Iurii Andreevich (2007) Protivoojarnii zanaves, Patent rosiiskoi federacii, RU 2 351 378 C1.
6. Seitlinger Gunter, Sicherheitseeinrichtung bei Tunnelbranden (2002) DEUTSHLAND PATENT DE 101 27 091 A1.
7. Wagner Ernst Werner at al, (2003) Verfahern und Vorrichtung zum Loschen von Branden in Tunneln, Europaisches Patentamt EP 1 312 392 A1.
8. O. Lanchava (2019) ANALYSIS OF CRITICAL AIR VELOCITY FOR TUNNEL FIRES CONTROLED BY VENTILATION. *Mining Journal N1 (42)*, pp. 126-132, Tbilisi (in Georgian).
9. O. Lanchava, E. Medzmariashvili, N. Ilias, G. Khitalishvili, Z. Lebanidze (2009) Prospects of usage of transforming systems for extinguishing fire in tunnels. *International Scientific Conference “Advanced Lightweight Structures and Reflector Antennas”*, pp. 301-308, Tbilisi.
10. O. Lanchava, G. Nozadze, N. Bochorishvili, Z. Lebanidze, N. Arudashvili, M. Jangidze, K. Tsikarishvili (2014) Criteria for evaluation of emergency firefighting in transport tunnels. *“Transport Bridge Europe-Asia”, Materials of International Conference*, pp. 29-34, Tbilisi,
11. O. Lanchava, G. Nozadze, N. Arudashvili (2015) ANALIZE OF FATAL FIRES IN TRANSPORT TUNNELS AND MEASURES OF ITS PREVENTING. *Mining Journal N2 (35)*, pp. 85-89, Tbilisi (in Georgian).
12. O. Lanchava, N. Ilias, G. Nozadze (2017) Some problems for assessment of fire in road tunnels. *Quality Access to Success*, Vol. 18, S1, pp. 69-72, Bucharest.
13. N. Ilias, O. Lanchava, G. Nozadze (2017) Numerical modelling of fires in road tunnels with longitudinal ventilation system. *Quality Access to Success*, Vol. 18, S1, pp. 77-80, Bucharest.
14. O. Lanchava, N. Ilias, G. Nozadze, S.M. Radu (2019) Heat and hygroscopic mass exchange modeling for safety management in tunnels of metro. *Quality Access to Success*, Vol. 20, S1, pp. 27-33, Bucharest.